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Memo No: 523

TO: Engineering Department - Photo Intelligence File

FROM: [redacted]

SUBJECT: Photocorrelator Problem

REFERENCE: Memo No. 470, 5 January 1962

DATE: 26 February 1962

A. Introduction

The above referenced memorandum discussed briefly the general problem faced by several governmental photo-intelligence centers in the preparation of index plot maps for general reconnaissance imagery. The present memo describes in more detail the types of analysis and the probable configuration of equipment involved in the solution of an important portion of the general problem, i.e. the plotting of image areas covered by conventional "instantaneous" aerial photography.

Following the general approach suggested in Memo 470, we may visualize the equipment as having two stations, an illuminated viewing station for the photograph and a ground-coverage projector for the plot map. The equipment might appear approximately as indicated in Fig. 1. The photograph viewer has a set of movable cursors for outlining the photograph area and for selecting several points of interest within the outlined area. See Fig. 2. The ground-coverage projector consists of a table on which the plot map is placed and onto which a bright outline of the coverage area of the photograph and bright spot indicators for the points of interest are projected. The operator adjusts the projection parameters until the point-of-interest indicators best match their proper map locations. During the operation the outline automatically changes shape and location to match changes in the point positions. When satisfied, he either manually marks the location of the outline, initiates the automatic recording of coverage information, or both.

B. Rectangular Photographs

The most common type of aerial photograph by far is the rectangular "instantaneous" conventional photograph. This group includes [redacted] pictures but excludes pictures taken with panoramic cameras, continuous slit cameras or other imaging devices in which significant vehicle motion may occur during the formation of the image. STAT

This class of photographs is related to its coverage area by the rules of central projection, if the curvature of the earth is neglected as a first approximation. Thus, straight lines on the ground are projected into straight lines in the photograph, and parallel lines in the photograph project into radiating lines on the ground. Fig. 2 shows the relationship of the rectangular image to the ground coverage area in the plane-projection case. The projected shape and location of the ground-coverage outline changes in accordance with variations in the six degrees of freedom of the camera.

In the proposed equipment, the cursor indicators will shift to maintain their correct projective relationships within the ground coverage outline when camera parameters are changed. The operator's task is to adjust the camera parameters to obtain the best fit between the selected cursor locations and the corresponding map points. When the fit is obtained, the outline will very nearly match the exact coverage area of the photograph. While three points would serve to fix all six camera parameters in the pure plane projection, the presence of uncompensated relief displacements in the photograph will in practice normally require that a best fit be obtained for more than three points.

C. System Output

Once the control knobs have been set for a best fit on any photograph, the knob settings form a set of coordinates which entirely determine a first approximation to the vehicle location parameters as well as a complete specification of the photographic coverage. It is therefore feasible to record any set of data desired on a magnetic tape, punched card, perforated tape, typed print out, or other form for permanently cataloging the film data. Thus, for example, the photo correlator can make a magnetic tape file of the geographic coordinates of each corner of every photograph processed, or of the coordinate squares included or partially covered in every photograph. It might also print the principle-point geographic coordinates on a pressure sensitive tape to be attached to each photograph; it can, with the addition of an auxiliary plotter, automatically plot the outline of each photograph processed, together with its serial number on an index overlay master. Alternatively, the correlator may merely record the primary control settings directly on magnetic tape and leave the determination of all the related secondary data to a conventional general purpose computer. Since these alternate means of recording the system output affect the division of labor among the operating personnel, the correlator system, and any available general purpose computation equipment, an early step in the study program should be a general evaluation of the various schemes to determine the approach to be taken in the first machine.

D. Coordinate System

One of the central problems in the design of an economical photo correlation instrument will be the choice of coordinate system used in defining camera parameters. While it is obvious that data obtained in any of the possible coordinate systems may be transformed into any other, it should be remembered that the cost of the data transformation is highly sensitive to the particular transformation performed. Thus, the selection of coordinate systems which minimize transformation costs may be pivotal in determining the overall economic value of the system. There are three primary coordinate transformations involved in this system.

1. The first transformation is the operator's transformation of his visual picture into his desired control settings. The operator sees a number of bright spots and corresponding graphic symbols on a plane map. The spot locations differ from the symbol locations in both latitude and longitude. He has a set of six controls which introduce variations in the pattern of spots. For example, the latitude and longitude of the principle point, the overall scale of the picture, the apparent inclination of the camera vertical with respect to North, the convergence of lines parallel to camera vertical, the inclination of the camera horizontal and the convergence of the horizontal lines are all changed by various adjustments of the six control knobs as indicated in the projection on the base map in Fig. 2. Clearly, since seven

variables were listed as changing response to variations in six knobs, at lease one of the knobs must change two or more apparent variables. The ease and speed with which the operator can manipulate the six controls to obtain a match is highly dependent upon the extent to which he can mentally transform the observed pattern of errors into a logical plan of knob adjustments without performing a long series of cut-and-try operations. Thus, each of the six knobs should change the pattern of spots in a simple and distinctive manner with the least feasible disturbance to previously made adjustments.

2. Second is the display transformation of points on a two-dimensional rectangular photograph into the two-dimensional perspective plot of the coverage area on the plot map. This transformation must be made by the computer circuits of the system. If the actual display is generated by a cathode ray tube which may be moved with respect to the plot map for changes in latitude and longitude, the block diagram of the system will be approximately as shown in Fig. 3. Thus the two computers for the vertical and horizontal deflection voltages must accept the x and y signals from the cursor commutator and the six manual knob settings and generate voltages which will trace the desired outline on the tube face, then skip to each cursor spot in turn, and repeat the cycle to present a continuous display. Similarly, the latitude and longitude computers must use the six knob settings to calculate the desired position of the principle point of the photograph. It would be most convenient and least costly if each of the variable quantities could be made a fairly simple function of only one or two of the knob settings.

3. Finally, if the output of the photo correlator is to have maximum value, it is necessary to transform the display knob settings into the location and attitude of the vehicle at the instant of the photograph. This transformation will, at best, only give approximate data, since the best-fit operation is itself approximate and the extension of the coverage data to the aircraft location is a rather long-armed extrapolation in many cases. However, the possibility of reducing the correlation time and cost by using extrapolated flight path data as a first approximation to each

successive frame of a series should not be overlooked. It may be that the cost of a bi-directional transformation computer would be offset by operating savings. If so, the aircraft-location computer must also use the six knob settings as its input, and give as its output the camera location (nadir point coordinates), altitude, and three pointing angles.

It should be evident from the above discussion that the choice of the exact function to be controlled by each of the six manual knobs will have important consequences in the implementation of all three primary transformations. One of the important portions of a study program will determine an optimum set of control variables to best meet the above requirements.

E. Outline of Study

The study program recommended in Memo 470 consists of three major portions.

Step 1 will be an exact definition of the problem. The primary emphasis in this phase should be on the common rectangular instantaneous photograph described here. On the other hand, sufficient attention should be given to other forms of imagery in the order of decreasing immediate interest, so that the system design will not be limited in any fundamental way from later inclusions of more sophisticated imagery. Step 1 is expected to require approximately four man-months of senior engineer effort spread over a three month period. At the conclusion of Step 1, an overall prognosis with a very high confidence on the feasibility of the entire project should be available.

Step 2 will be the computer study. This step will require approximately six man-months of senior and staff engineer effort spread over approximately a three month period. Step 2 will overlap Step 1 somewhat.

Step 3 will be the preliminary equipment design phase, culminating in actual hardware specifications. This last step is estimated to require approximately two man-months of senior engineer effort in a two month period.

Thus, the entire study program is now expected to lead to definite equipment specifications and to require approximately twelve man months over a period of approximately six to eight calendar months. A very high-confidence forecast of success can be made at approximately the one-third point in the program.

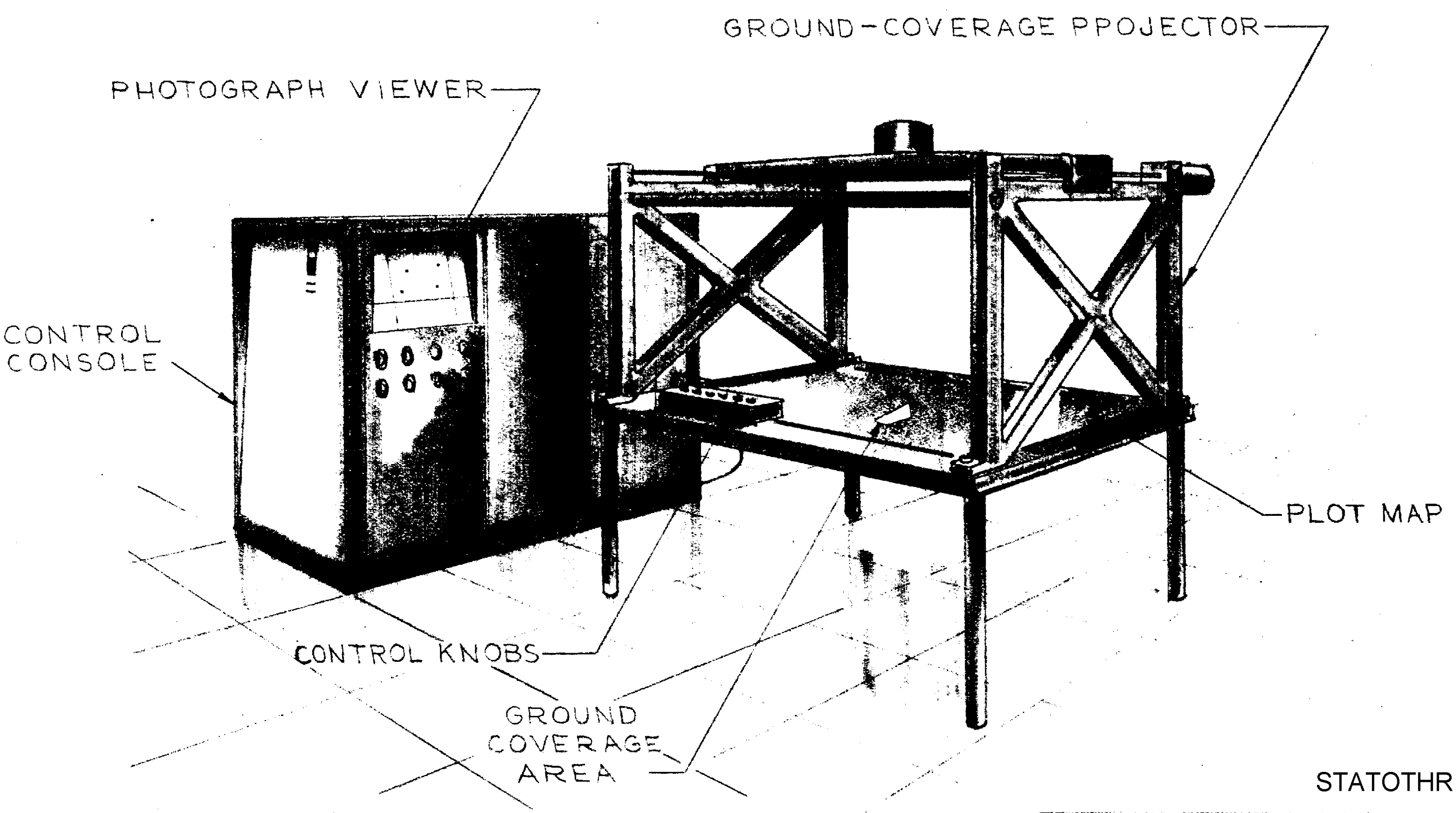

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FIGURE I
PHOTOCORRELATOR SYSTEM

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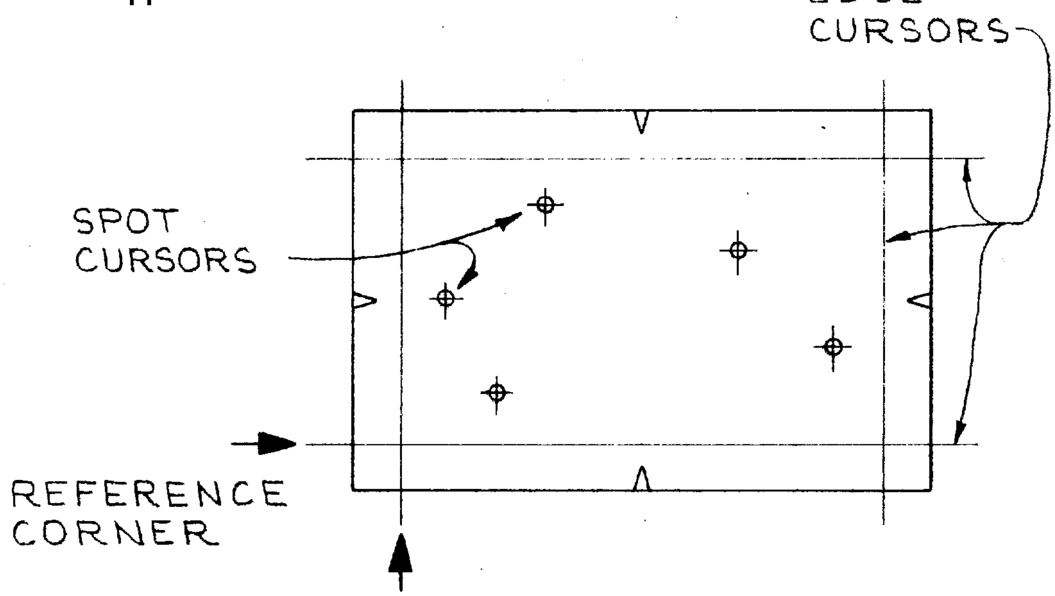
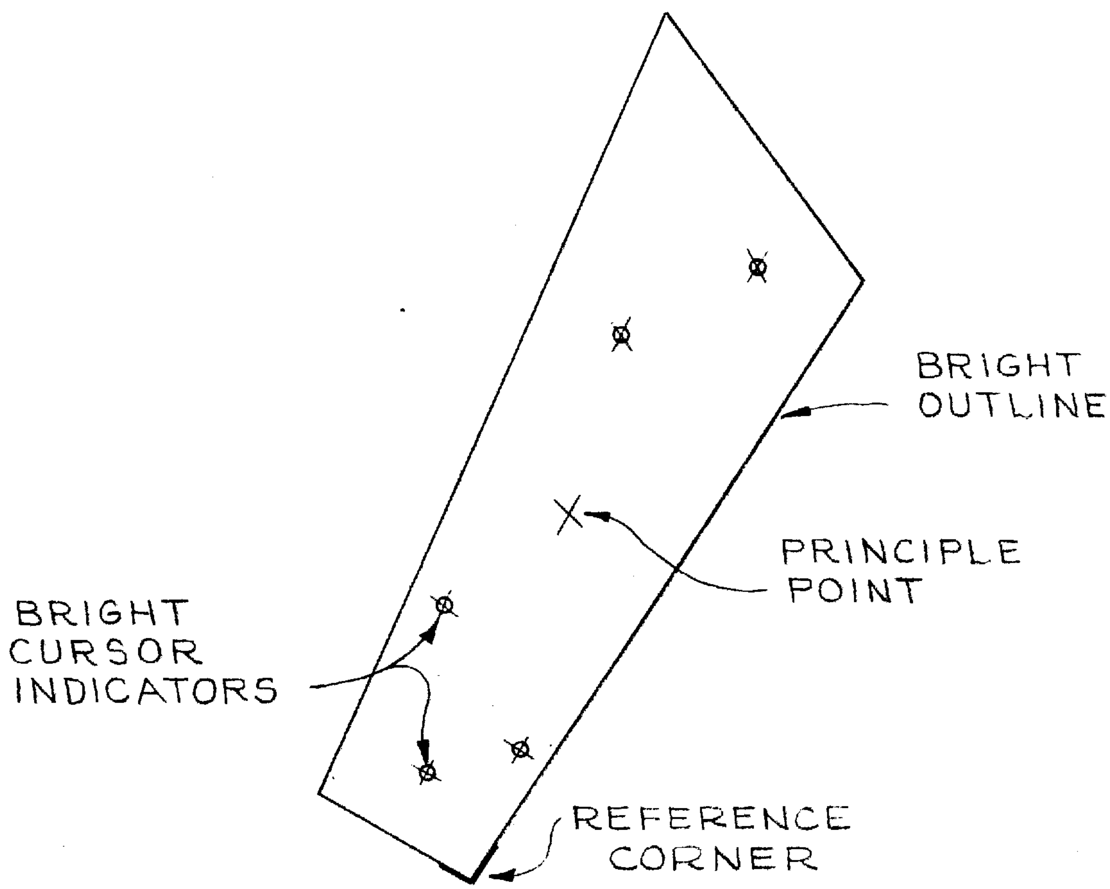


RECTANGULAR PHOTOGRAPH



GROUND COVERAGE AREA

FIGURE 2

RELATIONSHIP OF PHOTOGRAPH AND MAP

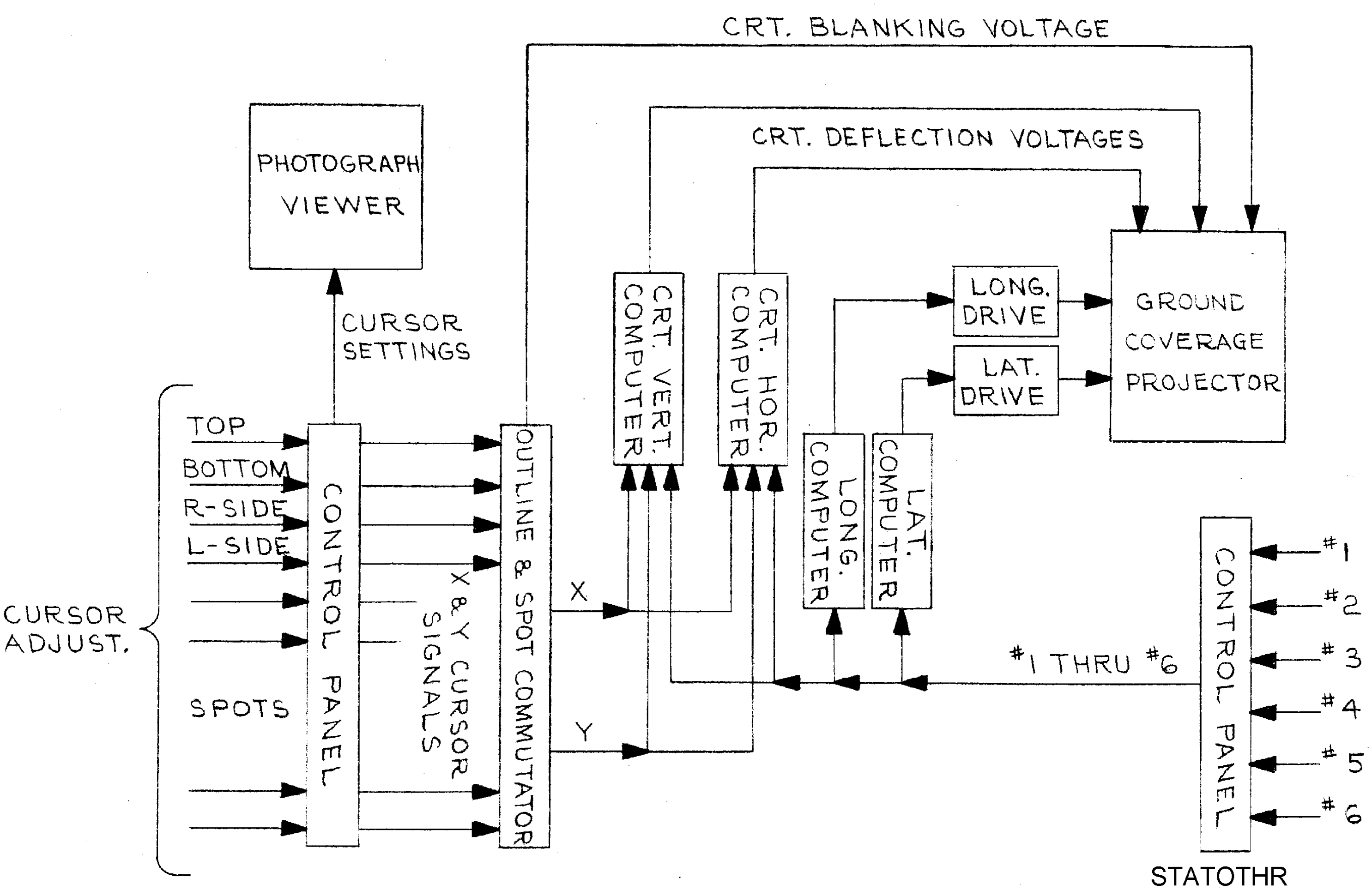


FIGURE 3

PHOTOCORRELATOR BLOCK DIAGRAM

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MEMO NO. 470

STATOTHR

TO: Engineering Department, Photo Intelligence File

FROM: [redacted]

SUBJECT: Photo Correlator Problem

DATE: 5 January 1962

A. Introduction

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In the course of discussions between representatives of various governmental agencies and [redacted] personnel, it has become apparent that a growing problem in photo-intelligence centers around the preparation of index plot maps. These plot maps consist of a base map with a direct or overlay plot of the coverage area of imagery obtained from aerial reconnaissance. The images themselves must also be titled and filed for possible restitution and interpretation in targeting and mapping.

Not only has the volume of this material increased to unwieldy proportions, but it has been intimated that the variety and complexity of the newer reconnaissance devices have made this cataloging quite difficult. It seems clear that a research and development program in this area would be valuable to (1) study the technical problems involved in partially automating the preparation of these plot maps, and (2) construct a prototype system with which this work might be done more rapidly and accurately.

B. Today's Problem

For some time, we have been told, the indexing of photo-intelligence material has been increasing in volume and complexity. There are at least three factors contributing to the growth in volume of data to be handled, and as many contributing to the complexity of the task of cataloging the data.

With the use of low-level, high-speed reconnaissance, the number of images necessary to cover a given area has increased considerably. The greater mobility of targets has necessitated more frequent reconnaissance. And the use of drone aircraft, satellites and other than conventional optics to obtain images has probably increased the number of means by which data can and is being obtained. The net result has been an influx of material which is delayed in interpretation because of a delay in cataloging.

One of the factors that has evidently increased the complexity of the photo-interpretation task is the addition of strip films to the conventional 9 x 9 inch photographs which have historically comprised the working medium for photo-intelligence.

Another factor to be considered is the esoteric nature of the imagery itself. In addition to the photographs obtained by conventional optics (which at least resemble what one might see with the naked eye) the photo-interpreter must now contend with images

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One of the complicating features most difficult to handle in manual cataloging stems from the unfamiliar projection [redacted] In the case of [redacted] for example, the image is recorded in [redacted] STAT STAT STAT STAT

[redacted] the reverse of the case of conventional optics. With the use of orbiting satellites, the rotation of the vehicle itself introduces a cylindrical coordinate system so that the ground area covered may be likened to a series of distorted hour glasses.

C. Technical Objectives

Plotting and cataloging of reconnaissance imagery is a task requiring a high degree of human judgement and hence not presently susceptable to full automation. On the other hand, the human cataloguer is severly hampered in correlating the raw unrectified imagery in the general case with the formalized base map by the difficulties of visualizing the projective relationship of the map and the pictorial image. This portion of the problem is fundamentally mechanical and repetitious and therefore suggests the possibility of considerable improvement through the application of semi-automatic equipment.

We may visualize a semi-automatic image correlator along somewhat the following line. The system would consist of two viewers, a control system, and small special computer. The imagery viewer is designed to hold and illuminate the films to be catalogued. It will have facilities for holding both roll and cut film and plates in standard sizes, adjustable boundary markers for delineating the areas of interest, several adjustable cursors for temporarily marking points of interest and such operator aids as magnifiers, provisions for marking overlays, etc.

The plot map viewer is designed to hold and illuminate the base map, data overlays, and a working plot overlay. It will also have a projector capable of projecting both line and continuous tone images onto the base map.

The control system will have provisions for manual or semi-automatic insertion of such input data as base map scale, projection, and location, type of image material and projection, vehicle location and orientation as well as all operating controls, and probably automatic output recording equipment.

The computer will employ a scanning device to examine the image area, it will perform a coordinate transformation to convert the image area to the map coordinate system and scale in accordance with its input data, and it will project onto the index map such selected image features as outline, points marked by cursors, or the entire image detail.

D. Operation

At the image viewer, the operator would select his negative or positive sheet or strip section and, by means of boundary markers, outline the useful area to be plotted. Controls would permit him to move a group of pointers or light spots to correspond with four or five identification features. A group of selector switches would then be used to introduce such known fixed factors as the coordinate system, lens focal length, as well as the scale and type of projection of the plot map. An additional group of controls would be used to introduce any information known about the six degrees of freedom of the aircraft, i.e. longitude, latitude, altitude, heading, pitch angle, and roll angle

On the plot map, the operator would see projected at approximately the correct location (depending on the amount and accuracy of the information set into the controls) an outline corresponding to the restituted coverage area of the image. Spots of light, appearing within the outline, would correspond to the identification points selected on the image.

Having related the light spots to the identification points shown on the plot map, the operator would adjust the six degrees-of-freedom controls to optimize the match. The outline would then be marked on the plot map (probably by hand tracing the projected outline), and the photo identification number inscribed within the outline. At the same time, the six control settings would be recorded on the original image (or on records associated with it) as an aid to photo-restitution at some later time.

Study Plan

In a study program to determine the economic feasibility of a semi-automatic image correlator, there are several areas which should receive particular attention.

1. <u>An exact definition of the problem</u>

   The first step in the program should be a study of the types of imagery in present use, and the types expected to be in use in the next few years. The study should determine a minimum set of basic transformation equations which will cover the practical range of imagery types and index map projections. The minimum practical accuracy of transformation ranges of input parameters, number of trial display points, desirability of plotting transformed grids should also be determined in this phase of the study.

2. <u>Computer study</u>

   Having defined the computation problems, the second study phase should determine optimum practical computer hardware. Here framing rates, accuracy, and range of parameters will govern the selection of analog, digital or hybrid techniques.

3. <u>Overall equipment study</u>

   The last phase of the study program should be a preliminary design study of the actual display and control equipment. At the conclusion of this phase, total costs, operating characteristics, and probable benefits from the use of the equipment may be determined with sufficient accuracy to determine whether further development should be undertaken.

Conclusions

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The type of study and prototype construction indicated in the preceding paragraphs fall well within the capabilities and interests of [redacted] There is every reason to expect that the technical problems involved will be readily susceptible of solution by engineering approaches such as those used in previous [redacted] cartographic systems.

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